CHEMICALLY BONDED AGGREGATE MOLD

This application claims priority from U.S. provisional application No. 60/409,789, filed September 11, 2002.

FIELD OF THE INVENTION

The present invention relates to the casting of metals. More particularly, the present invention relates to a method and an apparatus for the mold-removal casting of metals using a mold having low heat diffusivity.

BACKGROUND OF THE INVENTION

In the traditional casting process, molten metal is poured into a mold and solidifies, or freezes, through a loss of heat to the mold. When enough heat has been lost from the metal so that it has frozen, the resulting product, i.e., a casting, can support its own weight. The casting is then removed from the mold.

In conventional molding techniques, different types of molds of the prior art offer certain advantages. For example, green sand molds are composed of a particulate or granular material, typically sand, which is held together with a binder such as a mixture of clay and water. These molds may be manufactured rapidly for simple molds in an automated mold making plant. In addition, the sand can be recycled for further use relatively easily.

Other sand molds often use resin based chemical binders that possess high dimensional accuracy and high hardness. Such resin-bonded sand molds take somewhat longer to manufacture than green sand molds because a curing reaction must take place for the binder to become effective and allow formation of the mold. As in clay-bonded molds, the sand can often be recycled, although with some treatment to remove the resin.

In addition to relatively quick and economical manufacture, sand molds also have high productivity. A sand mold can be set aside after the

molten metal has been poured to allow it to cool and solidify, allowing other molds to be poured.

The sand that is used in an aggregate in sand molding is most commonly silica. However, other minerals have been used to avoid the undesirable transition from alpha quartz to beta quartz at about 570 degrees Celsius (°C), or 1,058 degrees Fahrenheit (°F). Such other minerals include olivine, chromite and zircon. These minerals possess certain disadvantages. Olivine is often variable in its chemistry, leading to problems of uniform control with chemical binders. Chromite is typically crushed, creating angular grains that lead to a poor surface finish on the casting and rapid wear of tooling. Zircon is heavy, increasing the demands on equipment that is used to form and handle a mold and causing rapid tool wear.

As an alternative to sand molds, molds made of metal are sometimes used. These metal molds are particularly advantageous because their relatively high heat diffusivity allows the cast molten metal to cool and solidify quickly, leading to advantageous mechanical properties in the casting. For example, a particular casting process known as pressure die casting utilizes metal molds and is known to have a rapid solidification rate. Such a rapid rate of solidification is indicated by the presence of fine dendrite arm spacing (DAS) in the casting. As known in the art, the faster the solidification rate, the smaller the DAS. However, pressure die casting often allows the formation of defects in a cast part because extreme surface turbulence occurs in the molten metal during the filling of the mold.

Moreover, since the manufacture of metal molds is relatively expensive, such molds possess a significant economic disadvantage. Because the casting must freeze before it can be removed from the mold, multiple metal molds must be used to achieve high productivity. The need for multiple molds in permanent mold casting increases the cost of tooling and typically results in costs for tooling that are at least five times more than those associated with sand molds.

In typical casting methods, rapid solidification of the molten metal is often desirable, as it is known in the art that with such cooling the mechanical properties of the casting are improved. In addition, rapid solidification and

cooling allows the retention of more of the alloying elements in solution, thereby introducing the possibility of eliminating subsequent solution treatment, which saves time and expense. To facilitate this rapid solidification and cooling, molds have previously been made of such materials and in such a manner as to possess a high heat diffusivity, a parameter that includes the contributions of thermal conductivity, heat capacity, and density and relates to the ability of the mold to extract heat from the casting. More specifically, heat diffusivity D (with units of $Jm^{-2}K^{-1}s^{-1/2}$) is the square root of the product of thermal conductivity K (J/mKs), density ρ (kg/m^3) and specific heat C (Jkg/K) and formally defined as $D = (K\rho C)^{1/2}$. As used herein, the heat diffusivity is the measure of the chilling power of the mold material.

These molds act as a "chill" to the molten metal, absorbing the superheat of the molten metal or permitting it to diffuse away and allowing the molten metal in the mold to quickly solidify or freeze. As used herein, "superheat" is used to refer to the temperature of a molten metal in excess of its melting temperature.

Nevertheless, for some types of molding processes, the opposite has often been found to be true. That is, it is sometimes desirable to use a mold that does not act as a chill in any manner to the molten metal during fill. This is particularly true if the molten metal is cast through the thin sections of a mold into thicker sections. The thermal energy of the molten metal is typically lost in the thin sections of the mold during the fill. This heat transfer can result in the molten metal becoming semi-solid and arrest the molten metal front, preventing the molten metal from advancing uniformly into the rest of the mold. Both sand and metal prior art molds act as a chill to the molten metal, albeit sand to a lesser degree due to its lower heat diffusivity.

As a result, it is desirable to develop a casting process and related apparatus that will provide for minimal heat transfer between the mold and the molten metal during filling while still allowing rapid cooling of the casting after the mold has been filled. Thus, there is a need to develop a mold material having low heat diffusivity while also allowing the rapid cooling of the metal casting after filling of the mold is complete as well as having the lower

costs, high productivity and the reclaimability associated with other aggregate molds such as silica sand molds.

BRIEF SUMMARY OF THE INVENTION

In one aspect of the present invention, a process for the casting of metals is provided. The process includes the steps of forming a mold from an aggregate comprising a particulate material and a binder, delivering a molten metal into the mold, contacting a solvent with the mold, cooling the molten metal such that it at least partially solidifies to form a casting, and removing at least a part of the mold.

In another aspect of the present invention, a method for producing a mold having low heat diffusivity is provided. The method includes the steps mixing a particulate material with a binder to form a moldable mixture, packing the mixture into a shaped pattern or tool to shape a mold or core, removing the mold or core in its green state from the pattern or tool, and drying the green state mold or core.

Alternative methods include (i) first partially curing the mold or core prior to removal from the patternwork or tooling, or (ii) first completely curing the mold or core in the patternwork or tooling. Such methods are preferred techniques because the potential for the distortion of the very weak mold or core in its green state is thus avoided.

In still another aspect of the present invention, a mold for the casting of metals is provided. The mold includes an aggregate comprising a particulate or granular material and a binder, wherein the mold may be eroded away using a solvent.

In yet another aspect of the invention, a method for forming a casting from a molten metal is provided. The method includes the steps of forming at least a part of a mold from an particulate material and a binder, delivering a molten metal into the mold, contacting said at least a part of the mold with a solvent, removing the at least a part of the mold, and solidifying and cooling the molten metal to form a casting.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may take physical form in certain parts and arrangement of parts or certain process steps, preferred embodiments of which will be described in detail in this specification and illustrated in the accompanying drawings, which form a part hereof and wherein:

FIG. 1 is a flow chart of the steps associated with one embodiment of the present invention.

FIG. 2 is a schematic side view of a layout of another embodiment of the present invention.

FIG. 3 is a flow chart of the steps associated with still another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, wherein the showings are for purposes of illustrating the preferred embodiments of the invention and not for the purposes of limiting the same, FIG. 1 illustrates the steps of the process of one embodiment of the invention. It is to be noted that the invention is suitable for the casting of any metal, including non-ferrous alloys based on magnesium, aluminum and copper, as well as ferrous alloys and high temperature alloys such as nickel-based and similar alloys. First, a mold is formed, step **10**. This step will be discussed in more detail below.

The mold is composed of an aggregate, which includes a particulate or granular material **12** and a binder **14**. The particulate material **12** includes a material having a minimal density, minimal thermal capacity and minimal thermal conductivity (i.e. minimal heat diffusivity) to reduce the heat that is extracted from the cast molten metal. By minimizing the heat that is extracted, the molten metal does not solidify prematurely and thus flows smoothly into all portions of large molds including the thin areas thereof. The particulate material **12** will also preferably be non-toxic and environmentally friendly, be compatible with water, have a Mohs hardness of 5 or above to prevent degradation and wear and be electrically neutral. The particulate material **12** also preferably has a low coefficient of thermal expansion and no

phase change, allowing use of the mold in high temperature applications while retaining high dimensional accuracy.

The aggregate of the cured (hardened) binder together with the particulate material is preferably absorbent of water or oil and permeable thereto.

Because the metal temperature for nonferrous alloys during metal casting is typically above 700°C (1300°F), cooling of the molten metal by radiation is also a significant factor to consider. In order to maintain all of the molten metal thermal energy in the molten metal itself during fill, the amount of heat lost due to radiation should also be minimized. A white aggregate, which has the highest expected reflectance and least heat adsorption, is therefore desirable.

The particulate material **12** may be composed of approximately spherical particles, which impart a good surface finish to the casting and minimize tool wear. The size of the particles should be fine enough to allow the creation of a good surface finish on the casting.

Exemplary materials that may be used for the particulate material **12** include, but are not limited to, crushed pumice particles (an amorphous foamed mineral); silica sand; ceramic, glass or refractory micro-bubbles; and mixtures of the above. Other types of volcanic glass such as perlite may also be used. Generally, any type of granular material having a quantity of trapped air between and/or within the packed particles and having a low heat capacity and thermal conductivity may be used.

One preferred material is a mixture of pumice and silica sand. The pumice may be, for example, siliceous in composition (rhyolite or dacite) or basaltic (reticulate). The addition of silica sand to the pumice serves several purposes. For one, the sand absorbs energy in the drying process and remains hot in the surrounding pumice, thereby facilitating moisture evaporation. Also, the blocky surface characteristics of the sand increase the green and dried mold strength. In addition, the hot silica sand, after the mold is cured and if immediately used to cast, aids the mold removal process by transforming the water to steam, thus uniformly increasing the removal of mold particles so as to more efficiently break the bonds between the pumice and

sand components. Finally, the silica sand aids in the removal or "stripping" of the mold from the mold pattern, increasing the green strength and the mass to help the mold pull more uniformly from the pattern. In such a blend, the size of the pumice particles and the sand particles are preferably within an order of magnitude or each other. Alternately, the aggregate may include pumice particles or with other additives, without the addition of sand.

Compared to the weight of a silica sand mold, the greatly reduced mold weight of the pumice/sand aggregate is important as well by reducing the amount of binder required, since less tensile strength is necessary to hold the mold together. Reduced local particle bond strength, due to the reduced binder content, assists in the later removal of the mold by water at lower application pressure. Any increase in water pressure is undesirable to avoid damaging the casting.

A specific granulated material suitable for use alone or in combination with sand in the aggregate of the present invention is KT 500 or KT 2500 High Density glass Micro-bubbles or a combination thereof, available from KT Minerals, Inc., located in Anthony, N.M. KT 500 and KT 2500 are non-hazardous glass micro-bubbles composed of an amorphous glass of sodium, potassium and aluminum silicate. The material may or may not be dielectrically neutral, has a pH of 7, is chemical resistant, is non-flammable, is non-hydroscopic, and is stable at temperatures ranging from -273°C to over 1350°C. In its micro-bubble form, the material has a specific gravity for KT 500 of about 0.66 g/cc and for KT 2500 of about 0.9 g/cc.

Another exemplary material that may be used as the particulate material is cenospheres, a constituent of fly ash. Cenospheres are inert, naturally occurring hollow microspheres comprised largely of silica and alumina. Although their physical and chemical makeup may vary, a typical cenosphere may contain, e.g., about 55-75 weight percent (wt.%) amorphous silica, 10-25 wt. % alumina, 1-10 wt. % sodium oxide, 1-10 wt. % potassium oxide, 0.1-5 wt. % calcium oxide and 0.1-5 wt. % encapsulated iron oxide. The exact composition of the cenospheres is not critical. Cenospheres are light in weight with a specific gravity ranging from about 0.70 to about 2.35, depending

on the grade. They have low thermal capacity and thus extract little heat from molten metal, allowing increased flow of molten metal in the mold.

The particulate material **12** is bonded with a binder **14** that is preferably water soluble to form the aggregate. Water is preferably added to the binder. This water aids in wetting the pumice particles of the aggregate to uniformly disperse the binder as well as providing the required "green strength" to allow the mold to be drawn from a pattern in its manufacture. As used herein, the term "green" is meant to include an undried or uncured state. Without the addition of water, the aggregate may become too dry to adequately bond.

Although the water increases the green strength of the mold, it may decrease the bond strength upon drying. This is thought to be due to the process whereby evaporating water from one section of the mold passes through an already cured section which has previously dried, thereby breaking down the dehydrated linked bonds between the binder and the particulate material. This effect is, in essence, a self removal of the mold. To minimize this effect, the cured mold should be permeable to allow water vapor to pass through it.

An exemplary binder **14** possessing the described characteristics is based on phosphate glass, a binder that is known in the art. Phosphate glass is an amorphous, water soluble material that includes phosphoric oxide, P_2O_5, as the principal constituent with other compounds such as alumina and magnesia or sodium oxide and calcium oxide. Other exemplary binders **14** include inorganic silicates, such as sodium silicate, and borates. Another useful binder is magnesium sulfate. Further exemplary binders **14** include systems wherein an organic binder, such as urethane, is added to a known inorganic binder and the organic binder is in the range of from about 1 weight percent (wt. %) to about 51 wt. % of the binder system. A suitable binder is available under the trade name CORDIS from HA International of Chicago, IL. More information concerning the binder can be found in applicants' recently filed application entitled "Mold-Removal Casting Method and Apparatus." This application was filed on July 7, 2003. It is incorporated herein by reference in its entirety.

Once the mold is formed, at step **10**, it is then cured either prior to or after removing it from the pattern at step **15** and subsequently positioned so that it may be filled with a molten metal, at step **16**. For example, the mold may be held above the floor of a foundry as known in the art. The molten metal fills the mold, using any appropriate method, at step **18**. For example, the mold may be designed to allow the molten metal to flow according to gravity, known in the art as gravity pouring or it may be counter-gravity filled using a pump.

After pouring the metal into the mold, at step **18**, the mold is subjected to the action of a solvent, such as by spraying, at step **20**. As mentioned, the binder **14** is soluble. Thus, the solvent dissolves the binder and thereby causes the mold to decompose **22**. As the mold decomposes **22**, the casting is exposed to the solvent, which causes the casting to solidify and cool rapidly **24**.

It should be recognized that a thin shell of solidified metal is formed at the interface of the molten metal and the mold almost instantly. Thus, when the solvent contacts the casting, it contacts the already solidified shell and not the molten metal directly. The solidified metal of the casting continues to be cooled by the continuous application of the liquid, and so acts as a chill to remove heat from the molten metal, thus solidifying the molten metal more quickly. At the same time, the already solidified metal of the casting is prevented from heating up significantly due to continual spraying or other contact with the solvent. As long as additional, relatively cool, solvent is delivered, the solvent is also prevented from heating up significantly.

The casting is thus separated from the mold and simultaneously solidified and cooled in a rapid manner, resulting in a casting that has been made with an inexpensive mold and has solidified rapidly, thereby having advantageous mechanical properties. Moreover, the delivery of a solvent in a manner such as spraying may have a strong zonal cooling effect on the cast metal, encouraging the whole casting to solidify progressively, thereby facilitating feeding and securing the soundness of the casting.

An exemplary solvent is water. Water is environmentally acceptable and has high heat capacity and latent heat of evaporation, allowing

it to absorb a significant amount of heat before evaporating. It can thus provide an optimum cooling effect to enable rapid solidification of the cast metal.

Other solvents may include liquids or gases that decompose the binder **22** and cool the cast metal **24**. For example, known quenching agents may be used with appropriately soluble binders. Moreover, a grit may be entrained in the cooling fluid (liquid or gas) and used to decompose the mold **22** by abrasion, at the same time as the mold is being washed away by the fluid. The grit may also serve a second purpose, namely to allow the cast metal to be peened by the grit as it is cooled **24**, yielding additional advantageous surface properties.

As the mold decomposes **22** when it is sprayed with the solvent **20**, at least some of the mold constituents may be reclaimed, step **26**. The particulate material and/or can be gathered **28** for drying and re-use. Moreover, the solvent can be collected **30**, filtered and recirculated for further use. In some systems, it may also be possible to reclaim the binder as well through a reclamation system as known in the art.

Turning now to FIG. 2, a schematic illustrating the apparatuses involved with the step **20** (referring back to FIG. 1) of subjecting the mold to a solvent is provided. A crucible or ladle **32** has been used to pour molten metal **33** into a mold cavity **34** that is defined by a mold **36** of the above-described aggregate and binder composition. A riser **38** is the last portion to be cast. One or more spray nozzles **40** direct one or more sprays of solvent **A**, such as water, at the mold **36**. The sprays, **A**, which can be termed jets, may be delivered in any suitable configuration from a narrow stream to a wide fan and may be a steady stream or a pulsating stream, as dictated by the particular application.

The delivery of solvent, i.e., the spray, may begin at the base of the mold **36**. The mold **36** may be lowered to allow the nozzle **40** to deliver the solvent in a progressive manner to intact portions of the mold **36** so that the mold **36** entirely decomposes. In the alternative, the mold **36** may remain stationary and the one or more nozzles **40** may be caused to move in order to progressively deliver a solvent jet **A** to decompose the entire mold **36**. In order to allow the entire circumference of the mold **36** to be contacted by the one or

more jets **A** for rapid decomposition, the mold **36** may be rotated or the one or more spray nozzles **40** may be moved about the mold **36**.

The rate and pressure of delivery of the jet **A** are of a setting that is high enough to decompose the mold **36**, yet low enough to allow the solvent to percolate through the mold **36** so that percolated solvent arrives at the cast metal **33** ahead of the full force of the jet **A**. In this respect, the mold should be permeable to the solvent during mold removal. For example, high volume, low pressure delivery in a range of about 0.5 to 50 liters per second, l/s (10 to 100 gallons per minute, gall/m) at a pressure ranging from 0.03 to 70 bar (0.5 to about 1,000 pounds per square inch, psi) may be advantageous.

In this manner, the percolated solvent causes the formation of a relatively solid skin on the cast metal **33** before the metal **33** is contacted by the force of the jet **A**, thereby preventing distortion of the metal **33** or explosion from excessive direct contact of the solvent with the molten metal **33**. The addition of a surfactant, as known in the art, to the solvent in the jet **A** or to the binder formulation may enhance percolation of the solvent through the mold **36**. In addition, at least some of the heat that is absorbed from the molten metal **33** by the mold **36** may increase the temperature of the solvent as the solvent percolates through the mold **36**, thereby increasing the energy of the solvent and causing it to remove the mold **36** more rapidly.

An additional consideration for the rate and pressure of the delivery of the jet **A** is the contact with the cast metal **33** once the mold **36** has decomposed. The rate and pressure of the jet **A** must be low enough to prevent damage to the casting **33**, but must be high enough to overcome the formation of a vapor blanket. A vapor blanket is formed by the evaporation of the solvent that has percolated through the mold **36** to contact the metal **33** in forming the skin on the casting **33**. The vapor blanket reduces the transfer of heat away from the cast metal **33** and is detrimental to the rapid cooling that is necessary to obtain the desirable properties and effects that are described above. Thus, it is advantageous to adjust the jet **A** to overcome the vapor blanket.

Control of the jet **A** may be exercised in at least two ways. The rate and pressure of delivery may be set to achieve all of the above

parameters, or two separate settings may be used. If two separate settings are used, one setting may be established for decomposition of the mold **36** and a separate, reduced setting may be timed to replace the decomposition setting when the jet **A** is about to contact the cast metal **33**. Of course, the manner in which the jet **A** is delivered, i.e., narrow stream, wide fan, steady flow, intermittent pulse, etc., affects the rate and pressure settings of the jet **A** accordingly.

The solidification of the casting **33** beginning at its base and progressing to its top allows the riser **38** to remain in a molten state for the maximum length of the time so that it may continue to feed the casting **33**. By feeding the casting **33** for a longer period of time, voids created by shrinkage of the metal **33** upon cooling are minimized. Solidification from the base of the casting **33** to the top also allows length or longitudinal changes to take place before solidification is complete, thereby eliminating any significant strain during solidification and any significant buildup of internal stress that often occurs in quenching.

It is important to note that a single nozzle **40** is not limited to a base-to-top direction of spray as described above. Depending on the application, it may be desirable to spray the jet **A** from the top of the mold **36** to the bottom, from a midpoint to one end, or in some similar pattern. In addition, the application of solvent is not limited to a single direction or nozzle. For example, two or more may be present, removing the mold **36** from multiple directions. Each can spray a respective fluid at the mold **36**. In this manner, the mold **36** may be decomposed more rapidly and uniformly, if desired in a particular application. Any number of nozzles may be present, as a great number of nozzles may be advantageous for large or complex molds **36** or a few nozzles may provide optimum coverage for other molds **36**. As with a single nozzle, the mold **36** may be rotated and moved vertically to allow complete distribution of the jets or the nozzles may be moved while the mold **36** and casting **33** remain stationary.

In addition, when multiple nozzles are used, it may be advantageous to time the function of the nozzles to complement one another. For example, a nozzle at the base of the mold may be engaged, thereby

spraying the jet vertically upwards at the bottom of the mold **36**. The bottom nozzle may be turned off and lower side nozzles may be engaged to spray at the mold **36**, and so on. Such coordinated timing of multiple nozzles may optimize the decomposition of the mold **36** and/or the direction of cooling of the cast metal **33** to provide the desired characteristics of the casting **33**. The water, or other fluid, can be sprayed at varying pressures and rates. A range that has proven satisfactory ranges from a minimum of about 4 liters (1 gallon) at about 3 bar (40 psi) to about 11 liters (3 gallons) at about 100 bar (1,500 psi).

It should also be appreciated that the casting can be further cooled after the mold is removed by continuing to spray the casting with a cooling fluid. The humidity of the environment does not appear to matter significantly in the removal of the mold. However, maintaining a high humidity or prewetting the mold may speed the mold removal process.

To manufacture the mold, certain steps outlined in Fig. 3 may be followed. First, a granular material **60**, binder chemical **62**, and solvent (if present) **64** are all selected. As stated one preferred particulate material can be a mixture of pumice and silica sand. A preferred ratio of pumice to sand is from 2:1 to 6:1 by volume, even more preferably about 3:1 by volume. The binder chemical and solvent (if present) are mixed to form a binder **66**. The granular material and binder are then mixed **68** to form an aggregate. The binder and particulate material can be mixed either by hand or with a mechanical mixer to form a uniformly moist aggregate mixture.

The aggregate is then packed into a pattern or core box as at **70** to form one part of a two-part mold having upper and lower mold halves. This step may include compacting the aggregate compress it in the pattern. This may be done by tucking and compressing the mixture by hand in a manner well-known to those skilled in the art. Excess compacted material may be removed from the open side of the pattern using a steel straight edge as a scraper (not shown).

In one embodiment, the aggregate mold may then be removed from the pattern in its uncured (green state), as shown at **72**. Depending on the shape of the pattern, this may be accomplished by flipping the pattern with

the open side of the pattern placed on a flat surface and the mold removed, leaving the compacted aggregate mold-half in its green state on the plate. The green state aggregate mold-halves may then cured or dried as at **74**, which may be done, for example, by placing the mold halves in either a conventional or microwave oven. Alternately, the mold may be used for casting without curing by pouring liquid metal into the mold **88** upon removal from the pattern. Additionally, the curing process is greatly facilitated by placing the mold halves on a perforated plate and drawing air through the permeable mold. Preferably the air is heated to a temperature of 50°C or more.

In a second embodiment, the aggregate mold is at least partially cured in the pattern, as at **76**. Once the mold is removed from the pattern at **78**, it is subsequently fully cured **80**.

In a third embodiment, the mold is fully cured while still in the pattern **82**. The mold is then removed from the pattern at **84**. In the last two described emobodiments, by curing or partially curing the mold or core in the pattern, the potential for the distortion of the very weak mold or core in their green state is avoided. A fully cured mold is produced **86**. Metal tooling therefore is capable of higher temperatures and therefore of faster production cycles. In any of these embodiments, once the liquid metal is poured into the mold at **88**, the resulting casting is cooled and solidified at **90**, as described above.

To illustrate the design and the effect of the process and apparatuses of the present invention, reference is made to the following examples. It is to be understood that the present invention is not limited to the examples, and various changes and modifications may be made in the invention without departing from the spirit and scope thereof.

EXAMPLES

Example 1 – Exemplary Embodiment of the Present Invention

A test specimen was formed by mixing 710 cm^3 (about 3 cups) of KT 500 pumice with 237 cm^3 (1 cup) Wedron 505 silica sand. The pumice and sand were mixed to form a uniform particulate mixture. A binder mixture was

produced using 15 grams HA Cordis 4615 with 5 grams of HA Cordis 4820BF in a 50% ratio with water. The binder mixture was mixed with the particulate mixture using an electric blender for three (3) minutes to form a uniformly moist green state aggregate. The green state aggregate was then hand packed and compacted about 20% into each of the two halves of a two-part pattern with a view to form two half molds. Each aggregate mold half was removed from the patternwork in its green state and dried. Drying was conducted using both a microwave oven (rated at 1.38 KW) using a three-minute cycle at the highest power as well as using a hot air oven with convection heating at a setting of 180 C (350°F) for 15-45 minutes.

The present invention is suitable for various alloys, including, for example, the 7XXX series aluminum alloys that normally have very long freezing rates and are not therefore normally castable in an aggregate type mold. The very fast solidification rates according to the present invention would enable the casting of these long freezing rate alloys. Due to the fast quenching rates, on the order of 30 to 50 °C per second (60 to 100 °F per second), the present invention may reduce or eliminate solution or aging treatment times, thereby providing a cost savings. The process may also be useful in 2XXX wrought series aluminum alloys that are known to be limited in their use for cast products because of the tendency of the alloys to hot tear, as well as inexpensive aluminum casting alloys such as 319 and 333 series.

By subjecting a mold that has a soluble binder to a solvent, the mold is dissolved, simultaneously causing the casting to solidify and cool. In this manner, a substantially cooled casting that has been separated from its mold is achieved rapidly. In using an aggregate made from a material that has a low heat diffusivity such as a mixture of pumice and sand, the present invention allows the mold to only define the shape of the cast product and not to extract heat from the casting. The extraction of heat is carried out by the controlled process of freezing the casting with a solvent in a directional manner to promote the maximum properties, maximum soundness, eliminate solidification strain and consequent need for stress relief of the casting. By carrying out the heat extraction in a separate step, the filling of the mold, whether by gravity pouring, tilt pouring, or by counter gravity filling, encourages

flow of the molten metal while minimizing premature solidification, allowing castings of complex geometry or thin sections to be achieved. By maintaining the superheat in the molten metal, the transformation of the metal to a semi-solid state during the filling process is retarded, thus allowing the molten metal to advance like a complete liquid rather than as a slurry or in a viscous flow that are typically experienced in the casting techniques currently used in the industry.

The benefits of such a uniform liquid fill include quiescent metal flow and mold filling, the ability to cast large heavy sections from a single metal inlet or ingate, the reduction of the advancing metal's resistance to flow in the mold because of premature partial solidification, thereby reducing the pressure necessary to instigate flow and reducing metal penetration into the mold, which results in undesirable surface finish, and the ability to fill large molds with thin sections.

In addition, the present low-chill molds will exhibit high dimensional stability. Such molds need not display any volume changing transformations and have low coefficients of thermal expansion. This is in contrast to molds that absorb high amounts of thermal energy during fill and solidification, which may distort due to the extensive regions of the mold changing temperature. For example, as discussed above, an alpha-beta quartz transformation can occur in silica sand aggregates, resulting in an expansion of over 1% at a temperature of approximately 570°C.

The application of a solvent need not be via a nozzle. One could, for example, direct the solvent to the mold via an impeller, over a waterfall, or other means. Furthermore, it is conceivable that a binder and solvent combination could be developed of such effectiveness that the mold could be removed without rapid movement of the solvent, such as by dipping the mold into a bath of the solvent. In such a system, the water or other solvent (whether flowing or stagnant) would progressively dissolve the soluble binder, slowly disintegrating the aggregate. The casting, in turn, would progressively solidify in a highly desirable rapid and directional mode as in other embodiments of the invention, to provide excellent properties and soundness in

the resulting final casting. Thus, while one means of applying the solvent is via a nozzle, other means are also conceivable.

Metal castings typically include feeders (risers) that allow molten metal to be fed to the castings as they cool and shrink, thereby reducing any voids caused by the shrinkage. Once a casting has cooled, the feeder must be cut off. With the present invention, the volume of the feeder is extremely small because of the efficiency of the directional solidification. In addition, it can be envisioned that at least one jet of solvent may be designed to deliver solvent at a rate, volume and area sufficient to cut off the feeder whilst the feeder neck is still in a semi-molten state, thereby eliminating an additional process step of the prior art.

While in the previous portion of the specification it was assumed that the entirety of the mold is made from a particulate material and binder, it should be appreciated that molds could be partially composed of an aggregate according to the present invention and partially from conventional mold materials. For example, a mold could be constructed with one wall being made of metal and three walls of aggregate according to the present invention. Alternatively, the mold could have three sides of conventional mold materials (such as silica sand; with either a conventional clay and water binder or a resin based chemical binder; or a metal) and one side made of an aggregate according to the present invention. Various other alternatives are also possible.

Further, the process, molds and equipment involved are low cost and environmentally friendly. Castings may be produced with a good surface finish and desirable mechanical properties in a rapid and economical manner, while the constituents of the mold may be reclaimed for further use.

The invention has been described with reference to preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.